Modeling the deep HETG observation of SN 1996cr
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SN 1996cr is located near the Virgo Cluster at a distance of 3.7 Mpc; it was discovered in the X-ray band and has been studied with archival and targeted data (Bauer et al. 2008).

SN 1996cr and SN 1987A are currently the only SNe known to have an increasing X-ray luminosity at a few years after the explosion. The likely scenario is that the progenitor created a wind-blown bubble in its vicinity, sweeping material into a dense shell outside the bubble, which is then shocked once the ejecta-forward-shock expands sufficiently.

A very deep, 485 ks, Chandra GO observation was taken of SN 1996cr using the HETG; this observation shows the velocity structure of the X-ray emission lines with reasonable statistics.

Here we compare the synthetic flux and spectra of a 1-D hydro model of SN 1996cr with the multi-epoch data sets that are available.

Below. Three epochs of SN 1996cr 1-D models and spectral data are shown. The lower panels show the measured data (black) with the synthetic X-ray spectrum of the hydro model overplotted (red).

The upper-left panels show radial profiles of the 1-D hydro model values of density (black), velocity (green), and temperature (red). The upper-right images show a schematic of the X-ray emission with shocked CSM in blue and shocked ejecta in orange. The SN core is in purple.

Below. The models calculated from the 1-D hydro model are shown by the curves for two energy bands. Measured points are plotted as well. We are in the process of “filing” the model to the data and have fluxes at a factor of 2. We expect further testing of the 1-D model (e.g. reducing the shell outer radius to reduce the line-time flux) will give agreement at the 30% level across the epochs. Note that we indicate when a further deep HETG observation might be taken in 2012 ...

Below. The 1-D model X-ray light curves from day 105 (top) and day 500 (bottom) are shown.

Above. The location of the forward shock (blue), contact discontinuity (red), and reverse shock (black) are plotted for the model; the model agrees reasonably with the XRT radio measurement indicated.

Above. SN 1996cr X-ray images are shown along with the 1-D hydro-based model for 2008. The general shape of the line features are similar in model and data although the data have a level at further structure.

The X-ray emission model includes emission from 55 shells; each with their own values of T and n (shown in the plot at right and labeled in the source background.)

As the Si component shows we are missing significant He-like Si emission in the current model. We expect this is likely due to lower temperature clumps in the system. Sources include a clumpy CSM, ejecta, and/or from B+F instabilities at the contact discontinuity (2D image at right)

To be continued ...

Above. SN - CSM interaction at $x \times 10^{17}$ cm

Below. SN 1987A optical X-ray component is shown here on the same distance scale as the schematic images of 1987C to emphasize how compact 1987C is especially given its high flux.